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Opportunity costs of conserving a dry tropical forest under REDD+: The case of the spiny dry forest in southwestern Madagascar

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ABSTRACT

Reducing Emissions from Deforestation and Degradation (REDD+) has been identified as a potentially cost-effective climate change mitigation strategy. The success of REDD+ in preventing deforestation and degradation in dry forests will depend partly on whether financial incentives for forest conservation can cover smallholders' opportunity costs of forgone uses of the forest. We therefore compared the opportunity costs of the main forest use activities (slash-and-burn agriculture or charcoal production) with potential benefits from the sale of carbon credits under REDD+ from a smallholder perspective for a case study in southwestern Madagascar. Calculations are based on an assessment of carbon stocks in the dry spiny forests as well as benefit and cost data from interviews with smallholders. To assess the risks and uncertainties associated with opportunity costs and the REDD+ benefits, we used a Monte Carlo modeling approach. We compare net present values for opportunity costs and potential community profits from REDD+ at discount rates of 5% and 20% over a project period of 25 years. Our results show that REDD+ community profits can outweigh the profits from charcoal production and the profits from slash-and-burn agriculture in 54–57% of the cases, despite opportunity costs being highly variable for both land uses. Charcoal production in particular has low opportunity costs as smallholders only engage in this activity when no other sources of income are available. The case study shows that potential REDD+ payments can provide sufficient financial incentives to preserve dry forests with low carbon stocks but relatively low opportunity costs of preservation.

1. Introduction

Conservation of tropical dry forests, which are widespread in subtropical regions predominantly in developing countries, is a global priority. These forests often support exceptionally high (endemic) biodiversity and are an important source of livelihood for rural populations (Kalaba, 2014; Portillo-Quintero et al., 2015). Tropical dry regions are historically characterized by a much higher population density than, for example, humid regions, resulting in high pressure on forests and historically greater deforestation rates than in rainforests (Skutsch and Ba, 2010).

REDD+ is a global mechanism designed to halt deforestation and its related carbon emissions and to compensate those who bear the costs of forest conservation for their efforts. One current focus of incentives under REDD+ lies on the provision of monetary or other co-benefits to communities or individuals implementing REDD+ activities on the ground (Boer, 2018). Pilot projects are currently being implemented worldwide to generate important input and knowledge for country-specific REDD+ frameworks.

Because dry tropical forests have relatively lower aboveground biomass (AGB) and thus lower carbon stocks compared to tropical rainforests (Becknell et al., 2012), they have so far rarely been the focus of REDD+ (pilot) activities (Blackie et al., 2014). There is a risk that once REDD+ is operational, carbon-dense rainforests will be conserved more readily by the REDD+ mechanism, while the conservation of biodiverse but less carbon-dense areas might achieve much less attention.

Whether financial incentives for forest protection provided under the REDD+ mechanism can halt deforestation in humid and dry forest regions depends primarily on the relation between the benefits of REDD+ and benefits of land uses, that is, the opportunity costs of protection (Hanley and Barbier, 2009). If REDD+ activities are planned in areas where land use by smallholders prevails, the perspective of land users will substantially influence the success or failure of REDD+. Evaluating benefit-cost relationships from their perspective can therefore provide important insights into the viability of conservation funding schemes on the ground. Until now, only a few empirical studies have evaluated such economic costs and benefits from the smallholder perspective (e.g. Borrego and Skutsch, 2014; Desbureaux and Brimont, 2015; Ickowitz et al., 2017; Pandit et al., 2017). Bellassen and Gitz (2008) showed that REDD+ can theoretically be a viable option from a smallholder perspective in regions where opportunity costs are low. In contrast, where

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current unsustainable land use practices, both on an industrial and on a smallholder scale, involve high opportunity costs, REDD+ will likely not be competitive (Sandker et al., 2010).

Less is known about the situation in dry tropical regions, where benefit-cost relationships are likely to differ substantially from rainforest regions. Here, REDD+ benefits are likely to be low due to the low forest carbon stocks, but opportunity costs may also be low due to low incomes from forest use. The only study in tropical dry forests to our knowledge is from Borrego and Skutsch (2014). So, this area warrants further investigation.

A further aspect that has so far received little attention in studies of REDD+ opportunity costs is the influence of risk and uncertainty related to land use decisions. To our knowledge, in the context of the REDD+ debate, no study explicitly addresses this issue, although a number of studies have shown in other areas that risk and uncertainty may strongly influence land use decisions (Benitez et al., 2006; Engel et al., 2015; Monge et al., 2016; Djanibekov and Khamzina, 2016). Thus ignoring effects of risk and uncertainty may result in erroneous estimations of benefit-cost relationships of forest conservation under the REDD+ mechanism.

To explore the viability of REDD+ in tropical dry forests from the smallholder perspective taking into account risk and uncertainty, the paper draws on a case study of the Mahafaly Plateau region in southwestern Madagascar. Madagascar is one of the world's least developed countries where 92% of the population live below the poverty line defined as an income of 2 US$ per day (World Bank, 2013). Despite the considerable benefits forests provide to the local communities, the region's forest cover decreased by 40% in the period from 1950 to approx. 2000 (Brinkmann et al., 2014; Harper et al., 2007). At the same time, Madagascar ranks among the top global conservation priority regions as its exceptional biodiversity is threatened by high deforestation rates (Myers et al., 2000). Especially the dry spiny forest ecosystem harbors a high density of endemic species, among them threatened flagship species like the radiated tortoise (Olson and Dinerstein, 2002). These dry forests are also an important livelihood source as they provide firewood, construction wood and non-timber forest products (Waeber et al., 2015). Given those circumstances, poor smallholders are the main agents of deforestation (Brinkmann et al., 2014) and are commonly expected to bear the largest share of the opportunity costs of REDD+ (see Ickowitz et al., 2017). Thus, the case of southwestern Madagascar is exemplary for a situation where low carbon stocks and high biodiversity values coincide and are threatened by high deforestation rates by a poor population generating very low incomes from deforestation.

The purpose of this paper is to assess the opportunity costs of avoided deforestation in tropical dry forests from a smallholder perspective for a case study in southwestern Madagascar. The case study assesses whether potential REDD+ payments provide sufficient financial incentives to preserve dry forests with low carbon stocks but relatively low opportunity costs of preservation. As risk and uncertainty from climatic variations as well as market prices may significantly impact on results, we explicitly address this issue. In the case that REDD+ payments are not sufficient to incentivize forest conservation, the research shows how much additional money would be needed from the perspective of smallholders, e.g. through payments for biodiversity conservation, in order to preserve dry forests. We specifically ask:

- What are the opportunity costs of reduced deforestation for the smallholders in the Mahafaly Plateau study region?
- How do these economic costs relate to benefits generated by carbon storage in the context of REDD+?

For calculating opportunity costs and benefits under REDD+ our study combines an assessment of the carbon stocks in dry spiny forests with economic cost-revenue calculations. In order to assess the risks and uncertainties associated with opportunity costs and the REDD+ payments, the analysis is done using a Monte Carlo modeling approach. Following Djanibekov and Khamzina (2016), we employ a second-order stochastic dominance approach for comparison of land use alternatives.

2. REDD+ and its implementation in Madagascar

2.1. The REDD+ mechanism

Development of the REDD+ mechanism by the UNFCCC (United Nations Framework Convention on Climate Change) has been ongoing since 2005. Its main objective is to mitigate climate change through providing incentives for reducing net greenhouse gas emissions from deforestation and forest degradation, the conservation and sustainable management of forests and enhancement of carbon stocks in developing countries (UNFCCC, 2007). A large and growing body of literature analyzes the progress in REDD+ policy development and implementation, and the (possible) consequences (see e g. Gupta et al., 2015; Ochieng et al., 2016; Vijge et al., 2016). The UNFCCC has provided methodological guidance for target countries to implement REDD+ prescribing that target countries should develop a national strategy or action plan, a forest monitoring system, a reference emission level and a safeguard information system (UNFCCC, 2010). Reference emission levels (REL) express the annual CO_2 equivalent emissions of a reference period and are used as business-as-usual (BAU) performances for a commitment period where future development trends are assumed to follow those of the past. Hence annual emissions below this level can be assessed as benefits of implementing REDD+ activities. Safeguards should ensure that detrimental effects on the environment or the local population are avoided (UN-REDD, 2011). An important first step in the set-up of the REDD+ framework for participating countries is to build national capacity, develop the national strategy or action plan and set up demonstration activities. With the implementation of demonstration activities, single REDD+ elements can be tested on a smaller scale and should provide important lessons for a national framework. These readiness activities are supported by the UN-REDD Programme, the Forest Carbon Partnership Facility (FCPF), and many other capacity building organizations. In 2016, 69 countries worldwide were implementing REDD+ readiness programs in cooperation with the FCPF or/and the UN-REDD Programme (http://www.forestcarbonpartnership.org; http://www.un-redd.org).

2.2. State of REDD+ implementation in Madagascar

Madagascar has put much effort into addressing the issues of deforestation and forest degradation by establishing and developing protected areas. At the Durban conference in 2003, the former president of Madagascar announced plans to more than triple the protected area from 1.7 to 6 million hectares (Angerand, 2013; Virah-Sawmy et al., 2014). This pledge was taken up in Madagascar's development roadmap “Plan d'Action Madagascar 2007-2012” (MAP). In line with those strategies, five REDD+ related or precursor projects emerged (Ferguson, 2009), mostly focusing on the establishment of those protected areas. Since 2008, when Madagascar joined the FCPF, it has established a REDD+ Technical Committee, a national REDD+ Readiness Coordination Office (BNC-REDD+) and submitted its final version of the Readiness Preparation Proposal (R-PP) in June 2014 and its Emission Reduction Program Idea Note (ER-PIN) in October 2015 to the FCPF (Weatherley-Singh and Gupta, 2017). Madagascar advocates a national REDD+ approach and is currently developing its REDD+ strategy. The pilot implementation of Madagascar's emissions reduction program starts in the eastern humid rainforest ecoregion with plans to subsequently extend it to other ecoregions. A legal framework is envisaged that clarifies the ownership rights of emissions reductions/carbon rights. Communities are the focus for REDD+ participants under this strategy (FCPF, 2015). To reward those that bear the costs of the reduction activities, Madagascar has provided a detailed REDD+

benefits distribution scheme in its ER-PIN that will apply to every REDD + related program in the future (FCPF, 2015). We draw on the technical provisions in the ER-PIN, especially for the benefit-sharing mechanism, to design the analytical framework for calculating potential benefits of forest protection under REDD+.

3. Materials and methods

3.1. Study region

The Mahafaly Plateau region is situated in the dry spiny forest ecoregion in southwestern Madagascar and covers approximately 800,000 ha. The semi-arid climate features an annual mean temperature of approximately 24 °C and variable annual rainfall of 300–600 mm (UPDR, 2003). Although approximately 203,400 ha of forest are protected in the National Park Tsimanampetsotsa (ANGAP, 2001), the Mahafaly Plateau region shows high deforestation rates, mainly outside of protected areas. Between 1973 and 2013, forest loss amounted to approximately 290,000 ha. This corresponds to a 45% decrease in forest area compared to 1973 and has led to fragmentation of forest patches and savannization (Brinkmann et al., 2014).

The local population in our study region practices predominantly subsistence agriculture, mixing arable farming and livestock keeping. Of the local population, 87% earns below 468,800 Ariary (approx. 200 US$) per capita and year (INSTAT, 2010). The infrastructure of the region is strongly underdeveloped, and basic health services, education facilities and clean drinking water supply are lacking (ILO Program, 2001). Due to the semi-arid climate and low soil fertility, crop yields are comparably low and seasonal hunger is widespread. In addition, due to variable rainfall and market price fluctuations smallholders increasingly face drought events leading to crop failures due to the impacts of climate change (Rahaingo Vololona et al., 2013).

Slash-and-burn practices lead in many regions to forest degradation as the cleared land regenerates to secondary forests after it is left fallow (Borrego and Skutsch, 2014; Mertz et al., 2009). However, in southwestern Madagascar slash-and-burn agriculture leads to deforestation because land typically does not regenerate once cleared, contributing to absolute forest loss (Ministry of Environment and Forests, 2014). There are two reasons for this: First, the harsh environmental conditions hamper regeneration and, second, cleared areas are under pressure from grazing and browsing that prohibit most regeneration. Slash-and-burn agriculture with maize (*tavy*, locally *hatsake or teteke*) as the main crop increased especially during the maize boom in the 1980s when prizes inflated by 460%, and the crop was exported predominantly to Reunion and Mauritius (Casse et al., 2004).

In addition, wood harvesting for charcoal production degrades the forest, especially near roads and settlements (Minten et al., 2013; Sussman et al., 1994). Charcoal production may secure incomes of poor rural households during drought years (Neudert et al., 2015). While in many other regions of Madagascar charcoal is increasingly produced from eucalyptus plantations, tree plantations are not common in the southwest due to low tree growth rates under the semi-arid climatic conditions. Logging of high-value timber, which is an important cause of deforestation in northern Madagascar (Ballet et al., 2009), does not occur in the southwest (Brinkmann et al., 2014).

3.2. Analytical framework

For estimating the economic opportunity costs and potential benefits of forest protection under REDD+, we applied a simplified analytical framework based on the returns to land approach, an established method for investigating the economic dimensions of land-use decisions that draws on farm-economic theory (Borrego and Skutsch, 2014; Naidoo and Adamowicz, 2006; Djanibekov and Khamzina, 2016). The basis of the assessment is one hectare of intact natural forest, which can be deforested or degraded, or, in contrast, protected.

For this, we first estimated profits for smallholders from one hectare of intact natural forest assuming that this hectare was used for slash-and-burn agriculture or charcoal production—the two main deforestation and degradation activities in our study region. For each of these two land use activities, we then estimated potential benefits for smallholders under an alternative REDD+ scenario where the hectare of intact forest is protected against the respective land use activity. Thus, we constructed two main comparisons: (1) slash-and-burn agriculture vs protection against slash-and-burn agriculture, and (2) charcoal production vs protection against charcoal production. We estimated net present values for a typical planning period of a REDD+ project.

For slash-and-burn agriculture and charcoal production we estimated annual profits from this hectare, which are the economic opportunity costs of avoided deforestation and degradation for smallholders for REDD+. Opportunity costs of resource use are defined as the foregone benefits of being unable to use this resource for the highest valued alternative purpose (e.g. Boardman et al., 2010; Hanley and Barbier, 2009). The opportunity cost concept is also used for planning purposes within REDD+ (World Bank Institute, 2011). Based on empirical field data, we characterized current practices for slash-and-burn agriculture and charcoal production in our study area and calculated the yearly profits per hectare as follows:

$$P_{lt} = R_{lt} - C_{lt} \tag{1}$$

where P_{lt} describes the profit per hectare, R_{lt} the sum of revenues and C_{lt} the sum of production costs for land use l and year t of one hectare.

In our analysis, we did not assume that charcoal production will follow slash-and-burn agriculture, or vice versa, as local informants confirmed that this is not common practice in the study region. Opportunity costs were expressed as costs per hectare and costs per ton of carbon. The former is the value that most likely influences local smallholders' decision-making, whereas the latter is useful for interpreting our results in the global REDD+ context. Section 3.4 describes how data was collected and calculated for the estimation of opportunity costs.

For the protection of forests under REDD+, we developed a plausible REDD+ scenario that allowed us to estimate financial profits per hectare for smallholders. We assumed that the study region was covered under a national REDD+ regulatory framework similar to the currently proposed national REDD+ approach (see Section 2.2) that rewards smallholders for protecting forests (FCPF, 2015). We further assumed that one hectare of intact natural forest was included under a previously agreed-upon BAU scenario assuming that the area would either be used for slash-and-burn agriculture or charcoal production. Under our REDD + scenario, we therefore assumed that all GHG emissions that are prevented by forest protection would be eligible to generate carbon credits under REDD+. The profits were then calculated as follows:

$$P_{pl} = S_l \times CP \times m \tag{2}$$

where P_{pl} is the profit per hectare from REDD+ for preventing alternative land use l over the total time frame, S_l the sum of avoided carbon emissions over the considered total time frame T from preventing alternative land use I (in tC/ha), CP the carbon price per tC, and m the share of total carbon benefits assigned to the local communities according to the benefit sharing mechanism (see Section 3.5). We then calculated annual profits from REDD+ as follows:

$$P_{plt} = \frac{P_{pl}}{T} \tag{3}$$

where P_{plt} is the annual profit from REDD+ for preventing alternative land use l per hectare, and T the considered total time frame. As all REDD+ implementation costs are assumed to be covered by the remaining share of carbon benefits that does not reach the local community, no further costs were considered (see Section 3.5). For the purpose of our study, we used the premise that the REDD+ framework

can be successfully implemented in our study area. Evaluating whether this is a realistic assumption or not was beyond the scope of our paper, as it would require not only detailed estimations of implementation and transaction costs, but also a more comprehensive, spatially explicit analysis on the landscape level (see Pandit et al., 2017 for an example).

Information about time-averaged carbon stocks for each land use alternative is required to calculate opportunity costs per ton carbon of slash-and-burn agriculture and charcoal production as well as to estimate potential benefits of REDD+ for smallholders. However, assessments of carbon stocks in tropical dry forests are rare (Meister et al., 2012) and were not available for our study region. Therefore, we carried out a biomass inventory to obtain a robust assessment of carbon stocks representative of the natural forest ecosystem of the Mahafaly region and estimated the amount of carbon that would be emitted if the representative hectare of forest were converted to slash-and-burn agriculture or used for charcoal production based on empirical field observations (see Section 3.3).

Accounting for differences between temporary benefit structures of the land use alternatives, we calculated net present values (NPV). The considered time frame of 25 years is one that is frequently used when calculating opportunity costs of REDD+ (Blaney et al., 2016). Benefits that are created in the future are discounted and summed up.

The calculation of the NPVs was based on the following formula:

$$NPV_c = P_{ct}\frac{i \times (1+i)^T}{(1+i)^T - 1} \tag{4}$$

where P_{ct} is the yearly profit from either projected land use or forest protection, i the discount rate and T the time frame over which profits for land use or protection are generated. Slash-and-burn agriculture and charcoal production are modeled to take place at the beginning of the considered time frame of 25 years, which results in higher NPVs for these activities than if they were carried out in later periods due to discounting of future benefits.

The discount rate i influences results decisively if the compared values are realized at different time points in the future. Low discount rates are commonly chosen for large-scale projects when the project is evaluated from a project planners' or social perspective. Discount rates chosen for developing countries are mostly higher than for developed countries as future generations are expected to be significantly less poor than the present ones (Smith, 2011). For the assessment of land uses in developing countries, mostly 10% is chosen (Grieg-Gran, 2008). Moreover, poor smallholders like those in the Mahafaly Plateau region must be expected to have a very high pure time preference rate, especially when faced with drought and seasonal hunger (Randrianarison and Wätzold, 2017). In order to depict the influence of the discount rate on results, we calculated NPVs at discount rates of 5% and 20%. The 5% discount rate would reflect a long-term planning perspective and 20% the perspective of short-sighted individual land users.

To conceptualize high uncertainties and variances, we used a Monte Carlo simulation approach to display the possible range and associated probabilities of results for opportunity costs and the REDD+ benefits. The Monte Carlo simulation, which was carried out using the excel-add in @Risk 6 (Palisade Corporation, 2013a), runs multiple iterations with a deterministic model structure and randomly sampled values from probability distributions of input data, yielding distributions of output data. The approach is suitable for analyses under risky or uncertain conditions and displays the possible range and associated probabilities of results. As input for the calculations, forest inventory data, information on land use practices from semi-structured interviews as well as price data from market monitoring were used (Appendix 1). Distributions were fitted in @Risk to existing raw data and the best-fitting distribution according to Akaike's Information Criterion was selected for the model (Akaike, 1974). Where necessary, distributions were truncated based on the minimum and maximum values of actual data. Correlations between input distributions were fitted within the model structure where suggested by expert knowledge. Sampling for the simulations was done with the Latin Hybercube option running 50,000 iterations (Palisade Corporation, 2013b). Consequently, we not only present mean values for most results, but also probability distributions of possible values for the Monte Carlo simulation.

For assessing the relative advantage of land use scenarios under risk and uncertainty, a stochastic dominance approach is suitable (Hardaker et al., 2015). The approach orders net present values of land-use activities according to their income distribution and is thus independent from preference functions (Djanibekov and Khamzina, 2016; Hadar and Russell, 1971). We applied a second-order stochastic dominance (SSD) approach, which compares the areas under the cumulative distribution function. Thus, forest conservation has a relative advantage from the perspective of the risk-averse farmer if:

$$\int_{NPV_{pl}^{min}}^{NPV_{pl}} FNPV_{pl}(u)du \leq \int_{NPV_{l}^{min}}^{NPV_{l}} FNPV_{l}(u)du \tag{5}$$

where NPV_{pl}^{min} and NPV_{l}^{min} are the minimum attainable net present values of prevented land use and land use, respectively. $FNPV_{pl}$ and $FNPV_l$ depict the cumulative net present values from forest protection and land use and u is the integration variable (Hardaker et al., 2015; Djanibekov and Khamzina, 2016). Assessing the relative advantage thus includes a visual comparison of integrals of cumulative NPV distribution functions.

3.3. Carbon stock assessments

We focused on aboveground biomass as it constitutes the largest carbon pool and has the highest likelihood of loss as a result of conversion to other land uses (FCPF, 2015). For the assessment of the carbon stock, we collected data in the northern part of Tsimanampetsotsa National Park and surrounding patches of undisturbed natural forest. The area constitutes the largest, mostly undisturbed forest patch in the dry spiny forest ecoregion. Following the approach by Plugge et al. (2014), we applied systematic cluster sampling (Köhl and Magnussen, 2016), where 27 sample locations were arranged in a rectangular grid of 1 km × 5 km in forested areas in the study region. At each sample location, 6 sample plots in a fixed geometric configuration were then established, amounting to 162 sample plots in total. Sample plots consisted of two concentric circles with radii of 7.98 m (200 m^2) and 12.62 m (500 m^2), respectively. The diameter at breast height (DBH) of trees with DBH ≥ 5 cm were measured inside the smaller sub-plot and of trees with DBH ≥ 15 cm inside the large sub-plot. Additionally, total and commercial heights were measured for a subset of trees.

For the calculation of aboveground carbon stocks, we estimated cylinder form factors $f_{1.3,\,s}$ of different species groups s in our study area based on expert knowledge. Then, we estimated the AGB of all individual trees as follows:

$$AGB_j = ba_{1.3,j} \times h_j \times f_{1.3,s} \times \rho \tag{6}$$

where $ba_{1.3,\,j}$, $f_{1.3,\,s}$, and h_j are the basal area (i.e. the cross-sectional area of the stem at breast height), tree form factor, and height of tree j and ρ a default wood density of 0.62 (IPCC, 2003). While the obtained estimates are only approximate, they follow the principle of conservatism and thus rather underestimate the AGB of individual trees. Subsequently, we summed up single tree AGB for each sample plot and extrapolated them to a per hectare basis. We then applied the default conversion factor of 0.47 to convert AGB estimations to aboveground carbon estimations (IPCC, 2006). As protected natural forests have relatively stable carbon stocks over time, we assume that these estimates are time-averaged over the period of 25 years.

Since slash-and-burn agriculture typically leads to deforestation in the study area, we assumed that all aboveground carbon stocks on the representative hectare of forest are emitted during conversion. In reality, most likely a small and negligible fraction of carbon remains for some time in incompletely burned wood on the site. Consequently, if

slash-and-burn agriculture was avoided on the representative hectare of forest, the complete aboveground carbon stock of the natural forest would be accountable for carbon credits under REDD+.

Charcoal production practices lead to forest degradation by selectively reducing the stocking volume. As the properties of the carbonization process vary and no register on charcoal production exists in southwestern Madagascar, the effects of charcoal production and their respective impacts on the forest carbon stock were estimated based on the literature and local informants in our study region.

For calculating the efficiency of charcoal production, i.e. how much charcoal can be produced from a given amount of wood, the following assumptions were made: Wood from some species, e.g. *Tamarindus indica, Acacia spec.* and *Cedrelopsis grevei,* with a sufficient diameter is preferred, while trees with a smaller diameter, shrubs and those species with inappropriate characteristics remain standing on the forest site. Ranaivoson et al. (2015) describes for the use of tamarind trees a minimum threshold diameter of 2.5 cm. We assumed that 10–50% of the AGB is used for charcoal production. In our study region, charcoal is usually produced in traditional kilns that have a low efficiency rate. These kilns are earth pits where wood trunks are piled in and covered with soil, dry grass and tree crown residues. Bailis et al. (2013) showed the efficiency of wood pyrolysis in specific chambers with ideal conditions to be around 50% of the raw material mass. But the efficiency of the pyrolysis process varies considerably depending e.g. on wood dimension, moisture and wood density (Pereira et al., 2016). Considering the low efficiency of the charcoal production in traditional pits, the use of fresh trees with a high water content and the limited opportunities for controlling the carbonization process, a lower efficiency ranging from 5 to 15% is realistic for traditional kilns in southern Madagascar. Hence, 85 to 95% of the wooden raw materials are assumed to be combusted and emitted to the atmosphere as CO_2 or CH_4 during the charcoal production process. Sparrevik et al. (2015) also states average efficiency rates of 10% for earth kilns in Brazil.

3.4. Profit assessments for slash-and-burn and charcoal production

The calculation of profits for slash-and-burn agriculture and charcoal production was based on field data collected in villages east and west of Tsimanampetsotsa National Park and the surrounding forest areas. Locals from these villages are likely users of the forest area covered by the carbon stock assessments. Due to the absence of sampling information, a convenience and snowball sampling approach was chosen. Attention was paid to selecting interviewees who practice slash-and-burn agriculture or charcoal production frequently as well as selecting interviewees who do it less frequently. Land use practices, crop yields, costs and labor input were assessed in 30 semi-structured interviews for slash-and-burn agriculture and 24 semi-structured interviews for charcoal production with local people actually practicing or having practiced the land uses. All costs and revenues have been converted to 2016 US dollars (1 US$ = 2670 MGA). Fixed costs for tools were neglected since they are likely to be negligible due to low mechanization of land use practices. Labor activities, even unpaid subsistence work, need to be valued for the comparison with REDD+ benefits. For valuing labor, the local daily wage of 4000 MGA or 1.50 US$ was used. This daily wage can cover the daily consumption needs of one five-member household in the study region of approx. 3865 MGA (INSTAT, 2010; Neudert et al., 2015).

Crop price information came from price monitoring of three local markets in the study region (Ambatry, Itomboina, Andremba). Local monitors collected price information at two-week intervals. We use price data for the harvesting seasons of maize (calendar weeks 12–20) and other crops (calendar weeks 14–22) from 2013 and 2014 in local units as input. As harvested crops are frequently sold to large-scale traders at discounted prices, we assumed that actual prices achieved from crop sale are 25% lower than market prices from small-scale trading. Harvested quantities and prices were converted from local units to comparable standard units (e.g. for maize, mung beans and charcoal). All socio-economic data collection was carried out with the help of local assistants who speak the local dialect fluently.

For slash-and-burn agriculture we assess revenues of the main crop, maize, and the most prevalent supplementary crops mung beans (Antsamby, *Vigna radiata*) and water melon (Vamanga, *Citrullus lanatus var.*), which may be intercropped with maize. Crops were valued at market prices assuming alternative selling for subsistence use. Direct monetary costs are seed costs, which are calculated at harvest market prices, and transport costs. Thus, seed, transport and labor costs were included in the calculation.

For charcoal production, the calculation was based on a standard charcoal bag which originally contained 50 kg of rice. Direct monetary costs are transport costs for rented oxcarts (used by the majority of charcoal producers interviewed) or no costs when bags are simply carried on the shoulder. Labor time was assessed per charcoal pit and then converted into values per bag.

Profits are calculated per hectare and per ton of carbon to facilitate comparisons. For calculating NPVs, we assumed based on local information that profits from slash-and-burn agriculture can be obtained in two subsequent years at the beginning of the time period considered for an alternative REDD+ implementation ($t = 1$ & $t = 2$). For charcoal production, profits occur in the first year only.

3.5. Profit assessment for forest protection under REDD+

We developed a plausible scenario for quantifying potential profits for smallholders under REDD+. We adopted the premise that the proposed national REDD+ framework of Madagascar, as outlined in Ministry of Environment and Forests (2014) and FCPF (2015), will be adapted in our study region. The technical provisions, especially those for the benefit distribution system, outlined in those documents are used as the best-available assumptions and provide the basis for our scenario. Under the proposed benefit distribution scheme, 50% of the total amount generated through carbon credits is destined for municipalities and population while the rest is intended to cover the burden of management, marketing, MRV, safeguard and other costs related to REDD+. Of the total benefits, 40% are designated for the “inhabitants to use as they see fit” to improve the livelihoods of communities (FCPF, 2015). Ten percent of the total benefits is paid to the municipalities to cover management costs of REDD+ schemes on the local level. The outlined approach is a preliminary benefit scheme that was developed and applied in the MAKIRA REDD+ pilot project. For our REDD+ scenario, we therefore assumed that 40% of the revenues generated through the sale of emissions reduction credits from one representative hectare are destined for rewarding the participating communities.

For our analysis, we further assumed that communities participate in the REDD+ scheme through the transfer of forest management rights to communities (Ministry of Environment and Forests, 2014), implying that land and tree tenure is secured, and protected areas can be managed for subsistence needs (e.g. use of NTFP). Activities under REDD+ therefore include mainly the protection of forests. In our scenario, communities were rewarded based on their GHG emissions reductions (result-based payments) in comparisons to the BAU. Thus, avoiding the conversion of forest to agricultural land through slash-and-burn or degradation of forest through charcoal extraction was assumed to generate benefits under REDD+. Furthermore, we assumed that the smallholders benefit directly from the REDD+ payments to the community. Hence, in our scenario benefits to individual smallholders from land use activities have the same importance as benefits to the community.

Given the importance of incentives for smallholders, we assumed that participating communities were awarded on an annual basis by an intermediate operator (e.g. NGOs). For calculating NPVs for REDD+ profits we assumed that the community received yearly payments of carbon credits for the avoided deforestation in contrast to the BAU

scenario. This benefit stream was then discounted to a NPV. The intermediate operator was delegated by the national government to implement REDD+ activities on a project scale. This includes the monitoring and verification of carbon stocks as well as the sale of carbon credits. The REDD+ program will be implemented for 25 years. We assumed that REDD+ is implemented on a national scale in Madagascar and therefore leakage is not relevant for our approach. We further made the simplified assumptions that all other necessary steps towards the implementation of our REDD+ scenario, such as the design and implementation of a monitoring system at the community level will be ensured. The approach to monitor the emission reduction as well as the real estimation of related costs remain beyond the scope of this paper.

The viability of a national REDD+ scheme in Madagascar and its regional application depends considerably on future carbon credit prices. As these are inherently impossible to know, we took uncertainties of prices into account by defining a range of possible carbon credit prices based on data from the voluntary carbon market. For this, we selected minimum and maximum values of annual global historical volume-weighted average prices between 2005 and 2015 (Hamrick and Goldstein, 2015). We then used a uniform probability distribution based on these values for the Monte Carlo simulation.

4. Results

4.1. Estimation of aboveground carbon stocks

Mean aboveground carbon stocks for the natural forest in the study region were 7.9 ± 1.8 tC/ha. These low stocks are a result of a low mean stand basal area of 9.7 ± 1.7 m^2/ha coupled with a low mean height of all trees of 3.65 ± 0.08 m. Fig. 1 shows the empirical distribution of the carbon stocks per hectare of all 162 sample plots. A log-logistic distribution, as indicated by the black curve in Fig. 1, was identified as the best-fitting distribution and used for the Monte Carlo simulation.

4.2. Profits from slash-and-burn agriculture

According to interview information, the households cultivate on average 2.2 ha with slash-and-burn agriculture. The fields are mostly located far away from the villages with 73% of interviewees stating they walked 1 h or more from their home. The field is mainly managed by a male member of the household with other household members helping during seeding and harvesting. Most households have permanent fields (*baiboho*) near their home villages, but slash-and-burn agriculture is in many cases vital to secure the household's survival or to generate cash for investments.

Shrubs and trees are cut from August to October and then burned.

Table 1
Cost-revenue calculation for slash-and-burn agriculture.

	Data	Unit	Mean	Stddev
1	Maize revenue	US$/ha/year	135.3	131.5
2	Mung bean revenue[a]	US$/ha/year	48.7	41.7
3	Watermelon revenue[a]	US$/ha/year	10.7	13.0
4	**Total revenue (l.1 + 2 + 3)**	**US$/ha/year**	**194.6**	**139.7**
5	Seed costs	US$/ha/year	2.5	1.0
6	Transport costs	US$/ha/year	6.1	4.6
7	*Variable costs (5 + 6)*	*US$/ha/year*	*8.6*	*4.8*
8	Labor time	Man days/ha/year	114.4	44.9
9	*Labor costs*	*US$/ha/year*	*171.4*	*67.2*
10	**Profit (4–7–9)**	**US$/ha/year**	**14.6**	**151.5**
11	**Profit (4–7–9)**	**US$/tC/year**	**−15.1**	**56.4**

[a] Intercropped with maize.

Crops are typically sown in November/December after the start of the rainy season. The main crop, maize, is sown with approx. 10 kg seeds per hectare. Seventy-seven percent of the interviewees intercrop maize with other crops, e.g. mung beans and water melons. Seeds for maize and other crops are mainly reused from the preceding harvest. During the growth period, 80% of the households monitor and protect their crops against theft and destruction by wild animals or birds, sometimes staying near the field day and night. Of those interviewed, 46% reported weeding the area at least once during the second year of field cultivation. Crops are harvested between April and July. The main reason for yield variations was seen in the varying amount of precipitation during the growing season. Most interviewees used the same area for 1–3 years, hence we assumed a cropping duration of 2 years for our model.

The economic analysis (Table 1) shows that the revenue from selling or subsistence use of crops is on average 194.6 ± 139.7 US$/ha varying depending on rainfall. In 77% of the modeled cases maize is intercropped with mung beans and watermelons. As an average of all cases, 70% of the per hectare revenues are earned from maize, while 25% are gained from mung beans and 5% from watermelons. Labor input varies between 14 and 282 man days/ha and results in labor costs of 171.4 ± 67.2 US$/ha on average. After paying labor costs, a profit of on average 14.6 ± 151.5 US$/ha/year is obtained. Due to the distributions of input data, the average value per ton of carbon is negative at −15.1 US$/tC, while the median is close to 0 and the mode is positive at 5.2 US$/tC (see Appendix 2).

4.3. Profits from charcoal production

Charcoal producers state that they prepare on average 11 pits per year, varying between 1 and 60 pits. Although charcoal production is possible throughout the year, most producers prefer to work in the dry

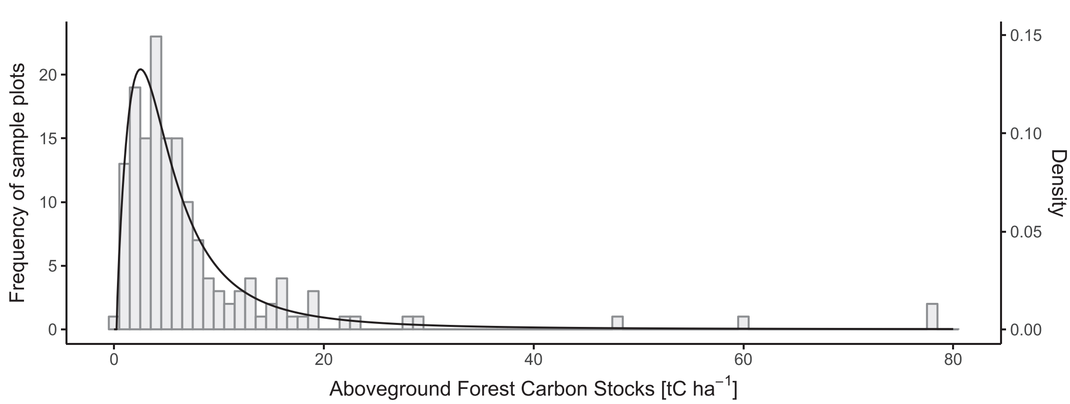

Fig. 1. Distribution of carbon stocks per hectare of 162 sample plots (histogram and y-axis on the left) and fitted log-logistic probability distribution for the Monte Carlo simulation (black curve and y-axis on the right).

season (March to October). Charcoal is produced mainly in the vicinity of villages where enough trees of appropriate species and diameter are found. Charcoal production is done mainly by young men from poorer families who do not own livestock. Interviewees uniformly state that charcoal production is a way to earn quick money when no other sources of income are available. The main motivation for starting charcoal production is drought leading to lack of food (*kere*) and the lack of other employment possibilities. Charcoal production is regarded as a laborious and exhausting activity with comparably little return, which is only possible for physically fit men. Thus, nearly all charcoal makers would stop the activity readily if other income-generating activities were available. However, nearly all interviewees stated that charcoal production in their villages has increased in recent years due to increasing incidences of drought, while suitable wood is increasingly difficult to find. Local weighting exercises showed that one bag of charcoal weighs on average 23 kg. Based on our assumptions on the charcoal production process and its efficiency as described in Section 3.3, one ton of carbon is released by the production of 8.8 ± 2.1 bags of charcoal. Considering the results of the carbon stock assessments, 16.8 ± 15.3 bags of charcoal can be produced on one hectare of forest.

For many charcoal producers selling requires additional effort and expenses. The charcoal often needs to be transported by oxcart to the villages or roads where selling takes place. If the oxcart is rented, the transport fees are high compared to the sale price of charcoal.

The cost-revenue calculation for charcoal production in Table 2 shows a low revenue per bag of 0.5 ± 0.3 US$/bag on average. The average transport fee amounts to 0.1 US$/bag. Labor input varies between 0.2 and 8.5 man days/bag, resulting in labor costs of on average 2.2 ± 1.4 US$/bag. Due to the high labor costs the profit is negative at −1.8 ± 1.4 US$/bag, indicating that charcoal producers are willing to accept labor remunerations lower than 1.5 US$/man day. The negative profit incl. Labor costs amounts to −29.8 ± 42.2 US$/ha. If labor costs are not valued, a profit of 0.4 US$/bag or 3.7 ± 2.7 US$/ha can be achieved, or respectively 7.0 US$/tC.

4.4. Profits from forest protection under REDD+

For estimating potential profits from forest protection under REDD+, we used a uniform probability distribution for carbon credit prices based on minimum and maximum values of annual global historical volume-weighted average prices between 2005 and 2015. Those were 3.3 and 7.3 US$/t$C0_2$e, respectively (Hamrick and Goldstein, 2015). The revenue per hectare further depends on the aboveground carbon stock and the alternative land use.

Avoided slash-and-burn agriculture generates revenues from carbon storage under REDD+ of 132.1 ± 107.9 US$/ha over the total time period of 25 years (Table 3). Assuming that 40% of the revenue is paid to the community (see Section 3.5) the community profit amounts to 52.8 ± 43.1 US$/ha. Avoided charcoal production achieves lower revenues and community profits as only 10–50% of the carbon stock would be released by charcoal production from suitable trees. The community profit is 15.9 ± 14.1 US$/ha.

Table 2
Cost-revenue calculation for charcoal production.

	Data	Unit	Mean	Stddev
1	**Revenue**	**US$/bag**	**0.5**	**0.3**
2	Transport costs	US$/bag	0.1	0.1
3	*Variable costs (l. 2)*	*US$/bag*	*0.1*	*0.1*
4	Labor time	man days	1.5	0.9
5	*Labor costs (4)*	*US$/bag*	2.2	1.4
6	**Profit per bag (1-3-5)**	**US$/bag**	**−1.8**	**1.4**
7	Production per hectare	bags/ha	16.8	15.3
8	**Profit incl. labor costs (1-3-5)**	**US$/ha**	**−29.8**	**42.2**
9	**Profit incl. labor costs (1-3-5)**	**US$/tC**	**−15.5**	**13.1**
10	*Profit excl. labor costs (1-3)*	*US$/ha*	*3.7*	*2.7*
11	*Profit excl. labor costs (1-3)*	*US$/tC*	*7.0*	*9.0*

Table 3
Revenues and community profits generated by avoided deforestation and degradation under REDD+ over the total time period of 25 years.

Scenario	Data	Unit	Mean	Stddev
Avoided slash-and-burn agriculture	Revenue	US$/ha	132.1	107.9
	Community profit	US$/ha	52.8	43.1
Avoided charcoal production	Revenue	US$/ha	39.7	35.3
	Community profit	US$/ha	15.9	14.1

Table 4
Net present values of profits of alternative uses of primary forest in the Mahafaly Plateau region.

Discount rate	%	5%		20%	
	Unit	Mean	Stddev	Mean	Stddev
Slash-and-burn agriculture	US$/ha	27.2	281.7	22.4	231.5
Avoided slash-and-burn agriculture (REDD+)	US$/ha	29.8	24.3	10.5	8.5
Charcoal production excl. labor costs	US$/ha	7.0	9.0	7.0	9.0
Charcoal production incl. labor costs	US$/ha	−29.8	42.2	−29.8	42.2
Avoided charcoal production (REDD+)	US$/ha	8.9	8.0	3.1	2.8

4.5. Comparison of profits from land use vs. forest protection

Table 4 and Fig. 2 compare the NPVs of the alternative land uses and forest protection at discount rates of 5% and 20%. As the confidence intervals illustrate, forest protection generates values with higher certainty, which even in the worst case do not fall below zero as the transfer of benefits to the local population is calculated as a share of total revenues under the REDD+ scenario. The high uncertainty of profits from forest uses becomes highly apparent: for slash-and-burn agriculture it is mostly related to maize yield variations and for charcoal production to the amount of carbon stored per hectare and labor input variations (Fig. 3).

In the overwhelming majority of cases REDD+ community profits generate higher values compared to charcoal production, even though the values generated by forest protection are low: 8.9 US$/ha at the 5% discount rate and 3.1 US$/ha at the 20% discount rate. In 99% of the modeled cases, forest protection at discount rates of 5% and 20% is more profitable than charcoal production. If labor costs are not valued, charcoal production generates higher profits at 7.0 US$/ha than forest protection, and REDD+ benefits can outweigh charcoal profits in 63% of the cases at the 5% discount rate, and in 35% of the cases at the 20% discount rate.

The average value for forest protection under REDD+ at a 5% discount rate is higher than the value for slash-and-burn agriculture (29.8 vs. 27.2 US$/ha). Given the modeled distribution, forest protection would still be more profitable than deforestation in 57% of the cases. In contrast, at the 20% discount rate, slash-and-burn agriculture has an average higher profitability (22.4 vs. 10.5 US$/ha), but still, forest protection is more profitable in 54% of the cases.

4.6. Risk and uncertainty in land use vs. forest protection comparisons

A comparison of cumulative distribution functions according to the SSD criterion yields comparable results: Fig. 4 confirms that the curve for forest protection under REDD+ is clearly located on the right side of the curve for forest degradation through charcoal production. This confirms the relative advantage for forest conservation even if labor costs for charcoal production are not considered. Comparing the

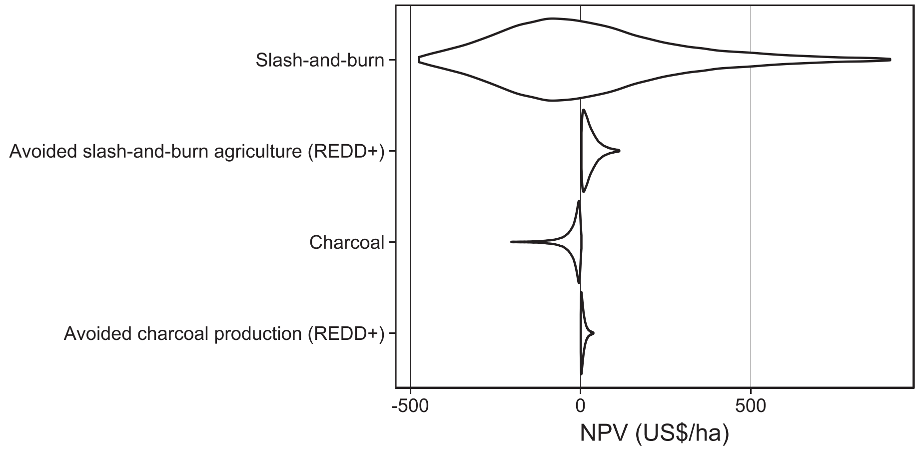

Fig. 2. Violin plots of net present values at a 5% discount rate for forest use and protection under REDD+ for the dry spiny forests.

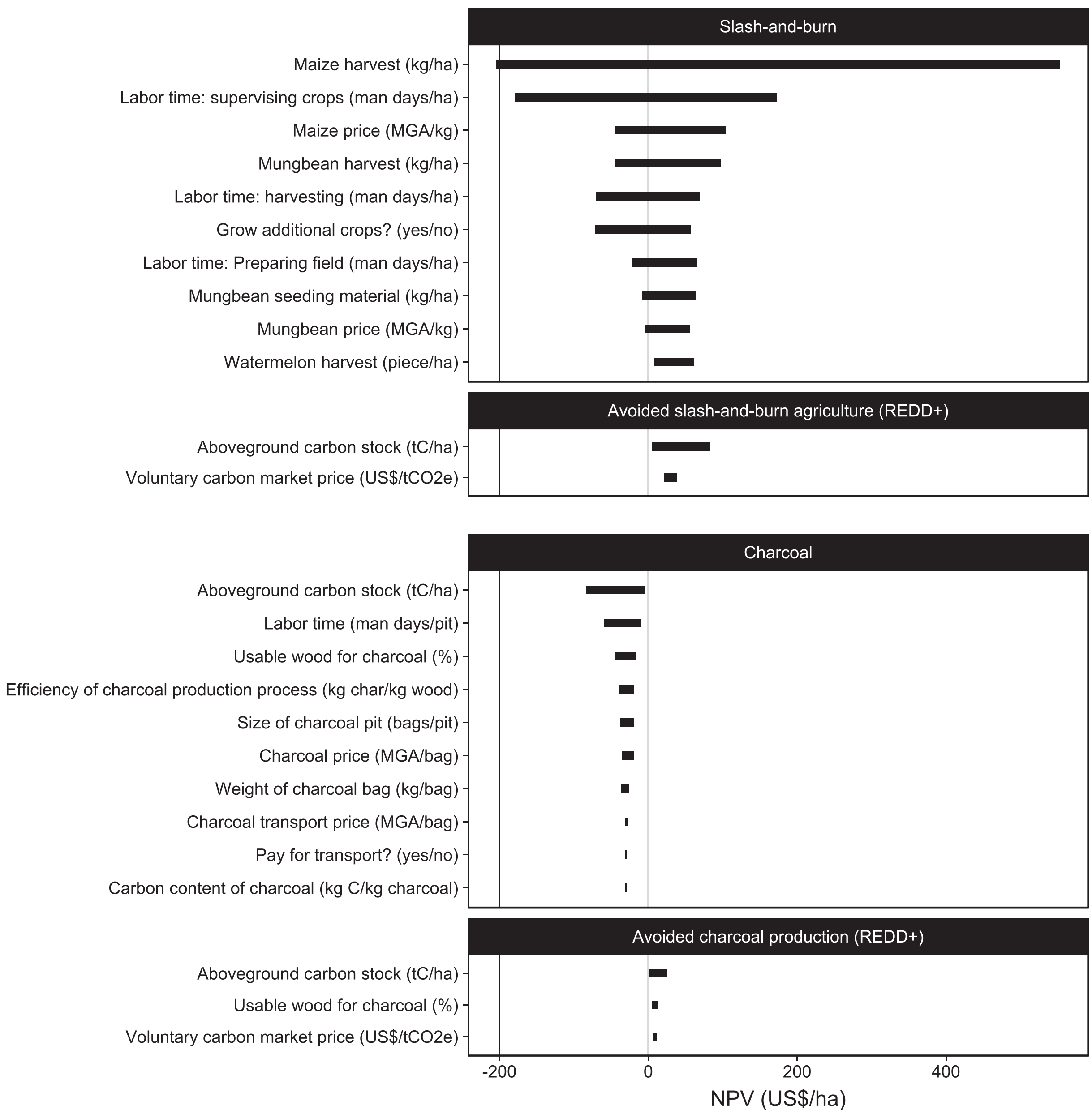

Fig. 3. Input variables influencing the results of net present values for forest use and protection under REDD+ according to Monte Carlo model calculations. Bars show variation of results based on the respective input variable, holding all other variables constant.

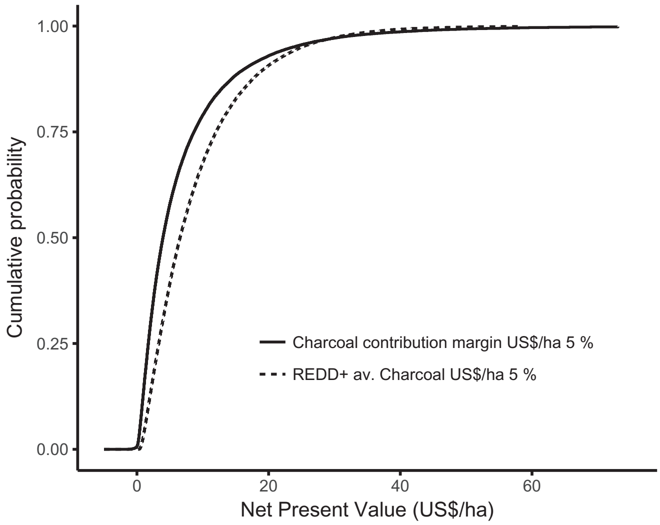

Fig. 4. Second-order stochastic dominance of charcoal production (without labor costs) and avoided charcoal production under REDD+.

cumulative NPVs for deforestation for slash-and-burn agriculture with forest protection (Fig. 5), the curves cross at a cumulative probability of around 0.55 and visually the areas between both curves below and above this value seem nearly equal. However, a numeric comparison showed that the area below 0.55 is slightly bigger than the area above this value, thus, yielding a slight relative advantage for forest conservation under REDD+.

5. Discussion and conclusion

In this study, we aimed to calculate the opportunity costs of reduced deforestation for smallholders in the Mahafaly Plateau region and assess how these economic costs relate to monetary benefits generated under REDD+ taking into account risk and uncertainty. For this, we compared profits from traditional land uses with potential REDD+ profits under a possible future national REDD+ scheme from a smallholder perspective using a Monte Carlo modeling approach and an SSD approach. Our results have important implications for the viability of forest protection under the REDD+ mechanism in dry forests in general.

According to the results of the NPV calculation, REDD+ community profits can outweigh the profits from charcoal production and the profits from slash-and-burn agriculture in 54–57% of the cases. With mean NPV values of 3.4 US$/tC for slash-and-burn agriculture and − 3.8 US$/tC for charcoal production, the results are located at the lower end of the result range of 0.15–339 US$/tC obtained by Phan et al. (2014) in a review of 32 studies on REDD+ opportunity costs worldwide. Table 5 presents a systematic comparison with the results from Ickowitz et al. (2017) who estimated smallholder annual opportunity costs of avoided deforestation on 17 sites worldwide. Keeping in mind some differences in methodology, opportunity costs and carbon density in our study are by and large lower than in the study by Ickowitz et al. (2017) for the dry forest sites in Tanzania. Table 5 also clearly shows that on humid forest sites the carbon densities are substantially higher, resulting in low opportunity cost per ton of carbon storage in comparison with dry forests. This result, leading to a relative disadvantage of dry forest sites is also underlined by Phan et al. (2014). Our results for the opportunity costs of slash-and-burn agriculture are in a similar range to the results of Ickowitz et al. (2017), while the opportunity costs for charcoal production are much lower than those of Ickowitz et al. (2017).

The results also underline that the NPV of opportunity costs, especially for slash-and-burn agriculture, is highly variable at 27.2 ± 281.7 US$/ha and depends primarily on crop yields and labor input. According to smallholders, variations in crop yield depend mainly on the variable rainfall in the study region. Our results for mean annual smallholder profits are also much lower than the values of 340 US$/ha

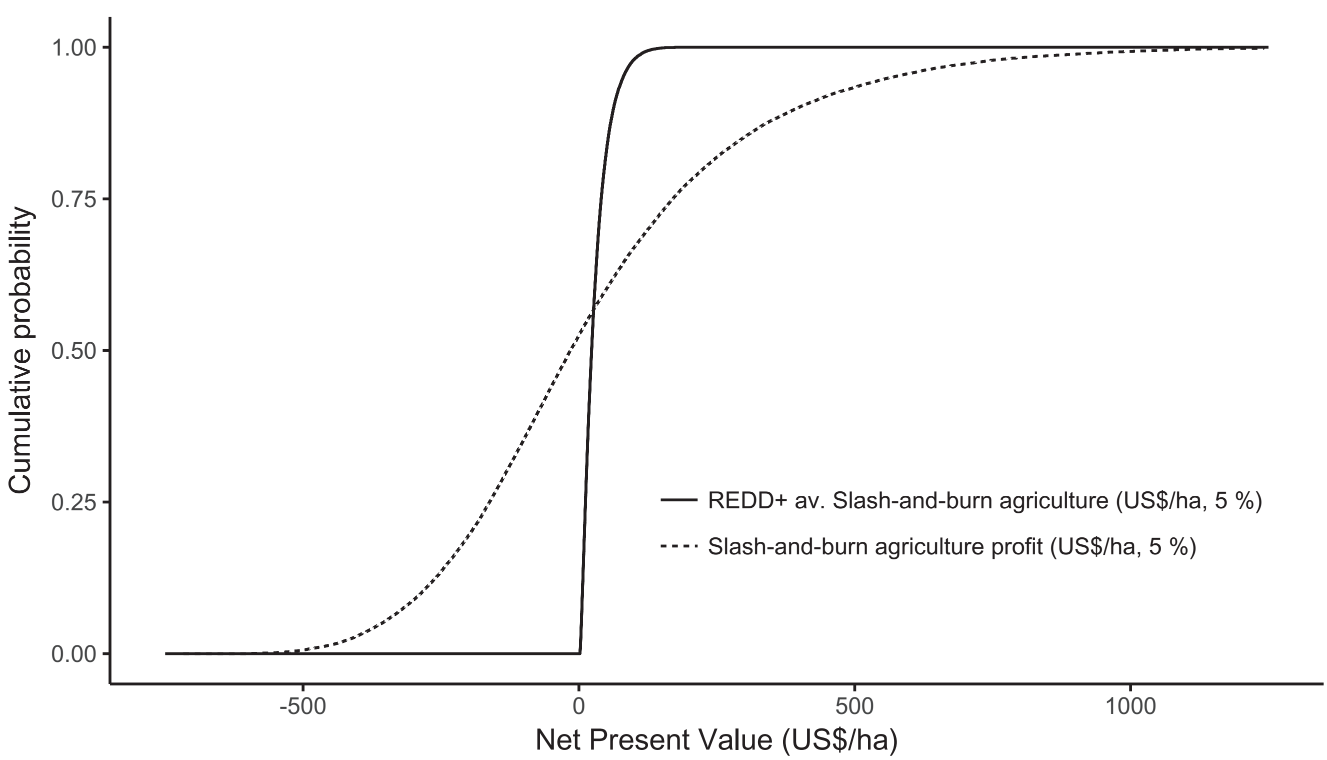

Fig. 5. Second-order stochastic dominance of slash-and-burn agriculture and avoided slash-and-burn agriculture under REDD+.

Table 5
Comparison of opportunity costs of forest conservation with a global study by Ickowitz et al. (2017).

	Location	Time horizon (years)	Discount rate (% p.a.)	Opportunity cost (US $/ha/a)	Present value of opportunity cost (US$/tC)	Carbon density (tC/ha)
Slash-and-burn agriculture	South-western Madagascar	25	5	186[a]	345.6[a]	8
Charcoal production	South-western Madagascar	25	5	3.7[a]	7.0[a]	8
Ickowitz et al. (2017)	15 sites in humid tropics (average)	30	9	446.5	29.8	174
Ickowitz et al. (2017)	2 sites in Tanzania (average)	30	9	228.2	525.65	16

[a] Without labor costs, consistent with Ickowitz et al. (2017).

mean annual net returns obtained by Borrego and Skutsch (2014) in an assessment of slash-and-burn agriculture in Mexico. In general, Naucler and Enkvist (2009) estimate that globally opportunity costs of slash-and-burn agriculture are below 7.5 US$/tC*year, which makes stopping slash-and-burn agriculture a low-cost option for avoiding carbon emissions worldwide. In our study, opportunity costs for slash-and-burn agriculture are, for 65% of the modeled cases, below 7.5 US$/tC*year.

For charcoal production, our results support the view that this land use option, with its very low economic profitability, is an inferior strategy for local households in times when no other sources of income are available. Even negative profitability results are obtained since charcoal production does not generate enough profits to pay off the assumed labor costs. Other estimates of opportunity costs for REDD+ focusing on charcoal production are rare in the literature, probably due to methodological challenges (McCall, 2015), despite the fact that charcoal production and fuel wood collection is the second most important reason for forest degradation in large parts of Africa (Kissinger et al., 2012). Thus, conserving forests under REDD+ is, in nearly all modeled cases, the economically better option for smallholders.

Although profits from current land uses were generally very low, the REDD+ community profits associated with forest protection were not able to outcompete land uses in all cases due to the low carbon stocks in the dry forest in southwestern Madagascar. The very low carbon stocks can be explained by the very low mean annual precipitation and the prolonged dry season in our study region compared to other dry forest regions, as there is a strong relationship between AGB/aboveground carbon stocks and climate (Becknell et al., 2012; Vieilledent et al., 2016). Our estimation of 7.9 tC ha^{-1} for southwestern Madagascar is plausible as it is of the same order of magnitude as those derived by Vieilledent et al. (2016) and Avitabile et al. (2016) using large-scale remote sensing maps. We came to this conclusion by extracting one pixel value at the location of each forest inventory plot from these maps. The average of these pixel values from the map of aboveground carbon stocks by Vieilledent et al. (2016) were 16 tC/ha and 8 t/ha (corresponding to 4.1 tC/ha) for the AGB map by Avitabile et al. (2016).

Despite REDD+ community profits being low and not being able to outcompete profits from current land uses in all modeled cases, REDD+ payments are less variable and thus, according to the results of the SSD approach, could offer a constant and reliable income for smallholders compared to the modeled current land uses (Fig. 2). The huge variability in profits from slash-and-burn agriculture is caused primarily by crop yield variations due to unpredictable precipitation. Drought events are associated with total yield failures and negative profits. Drought events and the variability of precipitation are likely to increase even more with climate change in southwestern Madagascar, further aggravating crop yield variability (Neudert et al., 2015; Rahaingo Vololona et al., 2013). In contrast to the risks associated with slash-and-burn agriculture, REDD+ payments can offer a more predictable income option for smallholders, even though the payments are relatively low. Moreover, the payment can be scheduled during the lean season to combat seasonal hunger and contribute significantly to household security, which would increase local incentives for participation (Neudert et al., 2015; Randrianarison et al., 2017).

Risk and uncertainty need to be considered in land use decisions related to REDD+. We contributed to the methodological debate on taking into account risk and uncertainty in the frame of REDD+ by applying the SSD approach to a forest conservation decision-making problem under high variability of precipitation and market prices. Although this approach has been applied to land use decision problems, it is novel to the REDD+ debate. In our results, we could show that there are slight relative advantages for forest conservation under the scenarios calculated if risk and uncertainty are considered. A static analysis using a calculation with mean values would not have revealed the strong risk implications, especially for the comparison of slash-and-burn agriculture vs. forest protection. Our study suggests that risk and uncertainty have important implications in REDD+-contexts. Further studies analyzing land use and forest protection decision problems are needed to improve our understanding of the impact of risk and uncertainty.

Due to the complexity of land uses and uncertainties in the local application of REDD+, our analysis was carried out under several assumptions and simplifications of the REDD+ implementation process. One of our assumptions was that the fixed percentage of 60% of the revenues generated through emissions reduction credits is sufficient to cover all REDD+ related costs (FCPF, 2015). This assumption is based on previous experiences with generated carbon benefits in REDD+ pilot projects in rainforest regions in Madagascar, where carbon stocks are considerably higher than in dry forest regions. Generated carbon benefits in dry forests would probably be much lower than in rainforests due to the much lower carbon stocks per hectare. As implementation and transaction costs would potentially be similar to those in rainforests, it is therefore highly questionable whether, in dry forests, all REDD+ costs could be covered by the designated share of 60% of carbon benefits. However, as REDD+ implementation is planned on a national scale in Madagascar, dry forests especially could benefit from implementation and transaction cost reductions through economies of scale. As Blackie et al. (2014) suggest, more research is needed on the relationship between REDD+ activities in humid areas and dry areas in the same country.

Furthermore, we assumed that local stakeholders are rewarded on a community basis and not as individuals following the proposed national benefit distribution scheme. This requires a fair and reliable benefit distribution system in which communities can equally access benefits and individual farmers are sufficiently incentivized to refrain from current unsustainable practices. However, recent studies have shown that especially the existing intra-community (hierarchal) structures and the often very poor understanding of them by external service providers that implement REDD+ activities locally (e.g. NGOs, state agencies etc.) pose a threat to the equitable distribution of benefits (Howson, 2017; Howson and Kindon, 2015). In this context, it must be ensured that the weakest community members are not excluded from participation under REDD+ and its benefits to successfully target emissions from forest degradation in areas like our study region.

In the study, we also assumed that land, tree and carbon tenure is secure which is an important requirement for REDD+ implementation (Sunderlin et al., 2014). However, globally, undefined ownership of forest land is still a serious obstacle to the implementation of REDD+ on the site level (Börner et al., 2010; Loft et al., 2017; Sandbrook et al., 2010). In southwestern Madagascar, many communities have legal rights under the community-based forest management scheme implemented in Madagascar since 1996, which is often criticized for not being fully operational (Hockley and Andriamarovololona, 2007; Pollini and Lassoie, 2011). For areas far away from villages, use and management rights to the particular forest area can be unclear, and the forest is often considered as de facto open access. Even if local communities do have legal rights, whether they are able to enforce them against others interested in deforesting the area remains questionable. Moreover, the process on the legal clarification of carbon rights in countries currently participating in a REDD+ (readiness) scheme has been slow (Loft et al., 2017). Theoretically, carbon rights could be linked to the right to land or be separated from it. Clarity in this context is seen as a requirement to attract donors. Madagascar's ER-PIN does not make any reference to such issues (FCPF, 2015). Thus, for southwestern Madagascar, as for the country as a whole, any potential REDD+ project would need to pay considerable attention to facilitate the definition and enforcement of community ownership rights (Chappelle and Angerand, 2013).

The risk of leakage in the context of slash-and-burn agriculture is considered low in the REDD+ approach of Madagascar (FCPF, 2015). We acknowledge the potential risk of displacing crop production to other regions and the possible reduced food availability involved. Actions to secure food availability and to avoid the potential displacement of production thus needs to be carried out when implementing REDD+ activities. This could possibly be achieved by increasing the productivity and improving the management of permanent agricultural systems. Due to high transportation costs of charcoal and the fact that in the study region charcoal production is a strategy for coping with income shortages when crop failure occurs, we assume the risk of displacement to be limited. Such income shortages are likely to be cushioned under our REDD+ scenario that assumes annual and constant payments to farmers.

Although the opportunity costs of REDD+ from the perspective of smallholders is a crucial benefit-cost relationship for assessing the feasibility of forest protection, our analysis does not present a full benefit-cost analysis in which all costs and benefits are valued monetarily. The protection of dry spiny forests in southwestern Madagascar under REDD+ would also deliver a number of other ecosystem services to the benefit of local smallholders, such as the provision of non-timber forest products (NTFP) (Andriamparany et al., 2014; Neudert et al., 2015), local climate regulation and habitat for many endemic species (Waeber et al., 2015), which may influence the benefit-cost relationship in favor of REDD+. Especially NTFP are an important side-benefit of forest conservation as forest species are used as an emergency food source, e.g. yams, and for medicinal purposes. Andriamparany et al. (2014) lists 6 yam species and 221 medicinal plants as NTFPs used in the dry spiny forest region.

Given the mixed economic results of REDD+ viability from the perspective of smallholders and the consideration of additional aspects in our case study, the question remains whether REDD+ can be viable in dry tropical forests. We could show that opportunity costs in southwestern Madagascar are in many cases very low, but still not low enough to clearly advocate REDD+ in the study region given the very low carbon stocks. Thus, the situation in dry forests is not necessarily more unfavorable to REDD+ compared to cases where high carbon benefits meet high opportunity costs, e.g. from commercial logging or oil palm plantations in tropical rainforests (Irawan et al., 2013). A possible option might be to combine REDD+ with payments for other ecosystem services and biodiversity. Globally, the value of dry forest biodiversity is especially important and studies found a positive willingness to pay among citizens of developed and developing countries (Markova-Nenova and Wätzold, 2017; Randrianarison and Wätzold, 2017). Moreover, a study in Indonesia showed that recent REDD+ project sites did not necessarily target areas with the highest carbon stocks but that most of the current activities are actually situated in areas important for biodiversity (Murray et al., 2015). Also for our study region, a combination of payments for REDD+ and for biodiversity might be a viable option to preserve both carbon stocks and endemic biodiversity in the dry forests of southwestern Madagascar. Our results indicate that relatively little money needs to be added to REDD+ payments to fully compensate current smallholder land-use practices for ensuring the long-term conservation of biodiversity in this area. Also on a global level, combining REDD+ with biodiversity payments to preserve forests in biodiversity-rich regions might be an effective option that warrants further investigation.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.forpol.2018.07.013.

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